

# Satellite Sea Surface Salinity Assimilation Improves the Representation of Upper-Ocean Thermohaline Structure and Variability in the NASA GEOS S2S 2 model

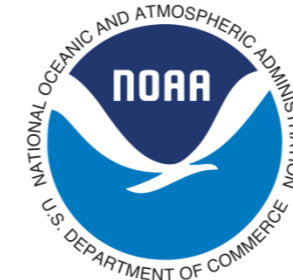
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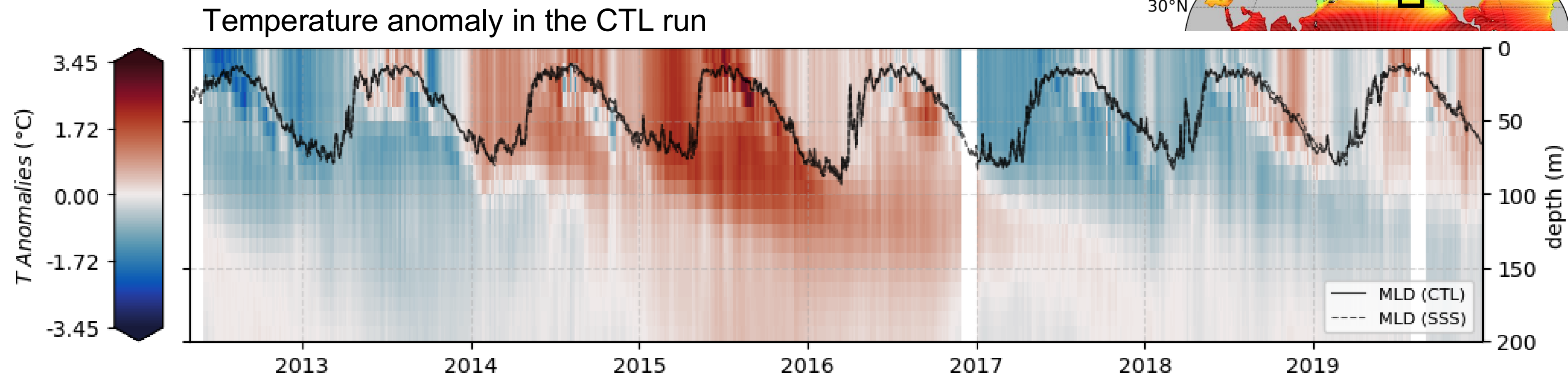
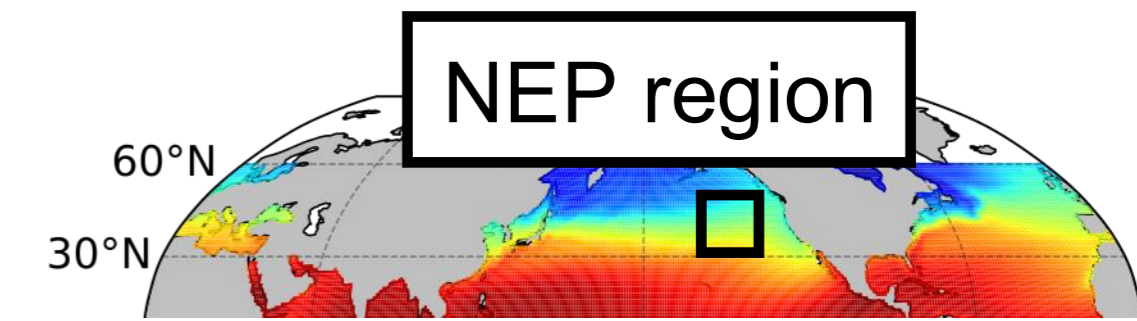
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# Motivation

- Upper ocean stratification depends on both T and S, yet SSS is weakly constrained in most coupled DA systems.
- Improved SSS representation in models may improve representation of stratification, with implications for
  - Ocean heat content anomalies in the mixed layer.
  - Surface and subsurface marine heatwave intensity.



# How does the SSS assimilation impact model output?

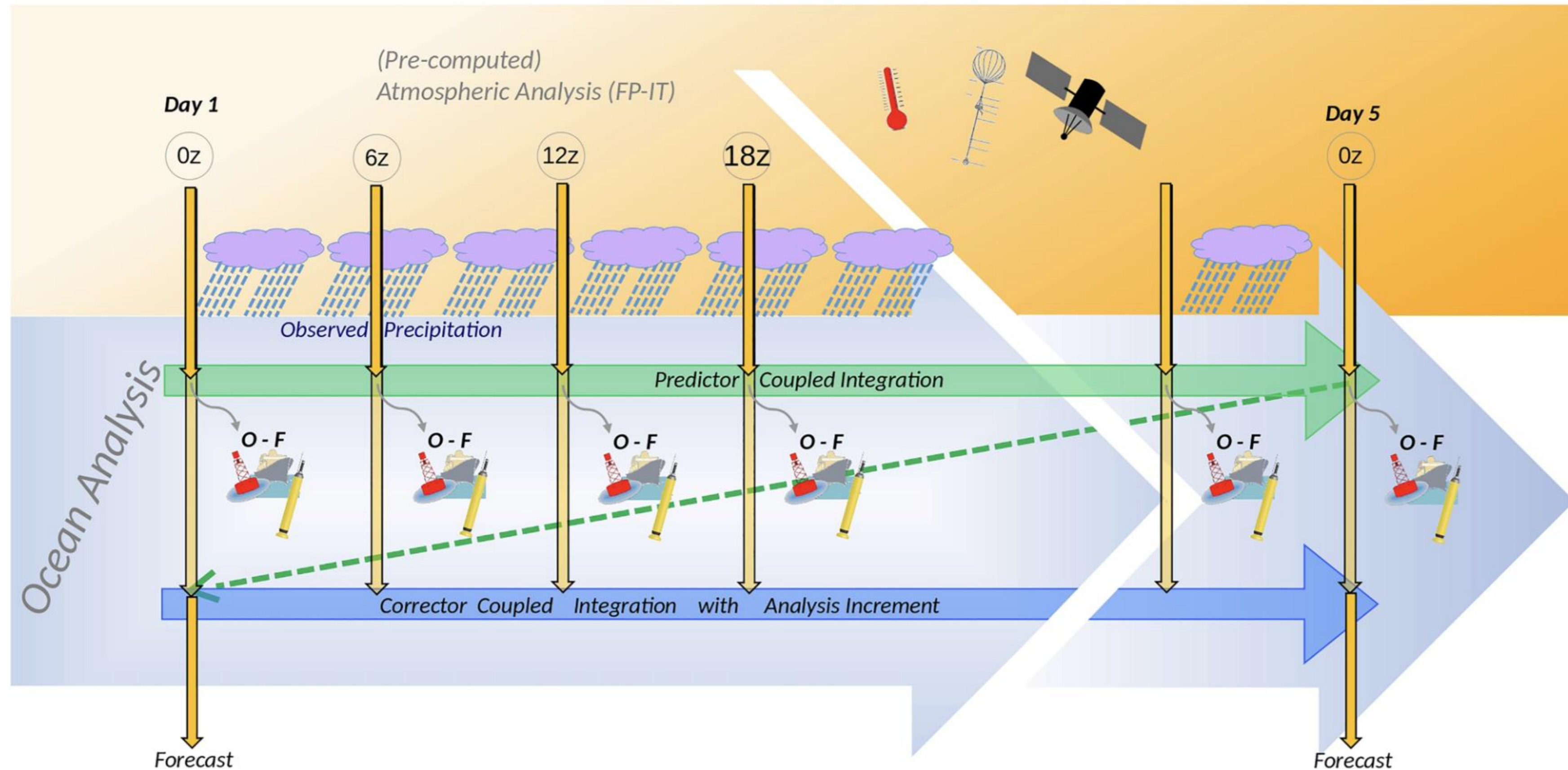
- Experiment Design: Model runs with (SSS) and without (CTL) SSS DA are compared to Argo profiles on various timescales



- Diagnostics:
  - Salinity
  - Temperature
  - Pycnocline stratification ( $N^2_{\text{pyc}}$ , estimated 15m below ML)
  - Mixed layer depth
  - Global seasonal variability of OHC

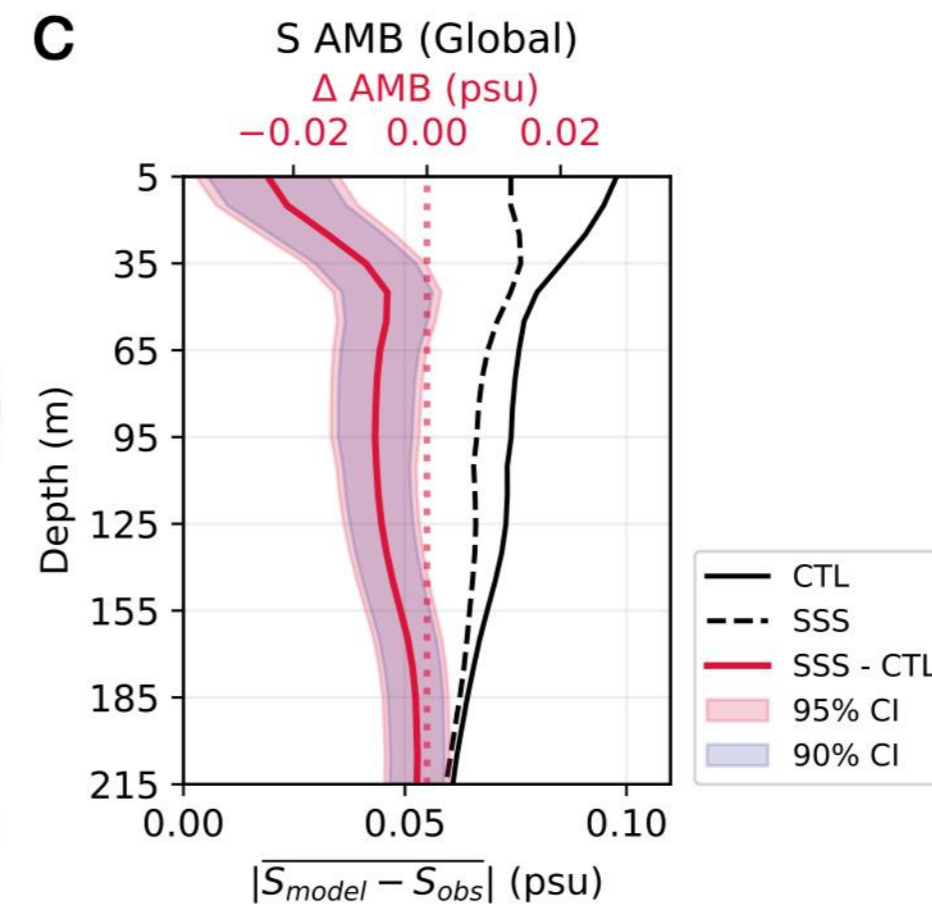
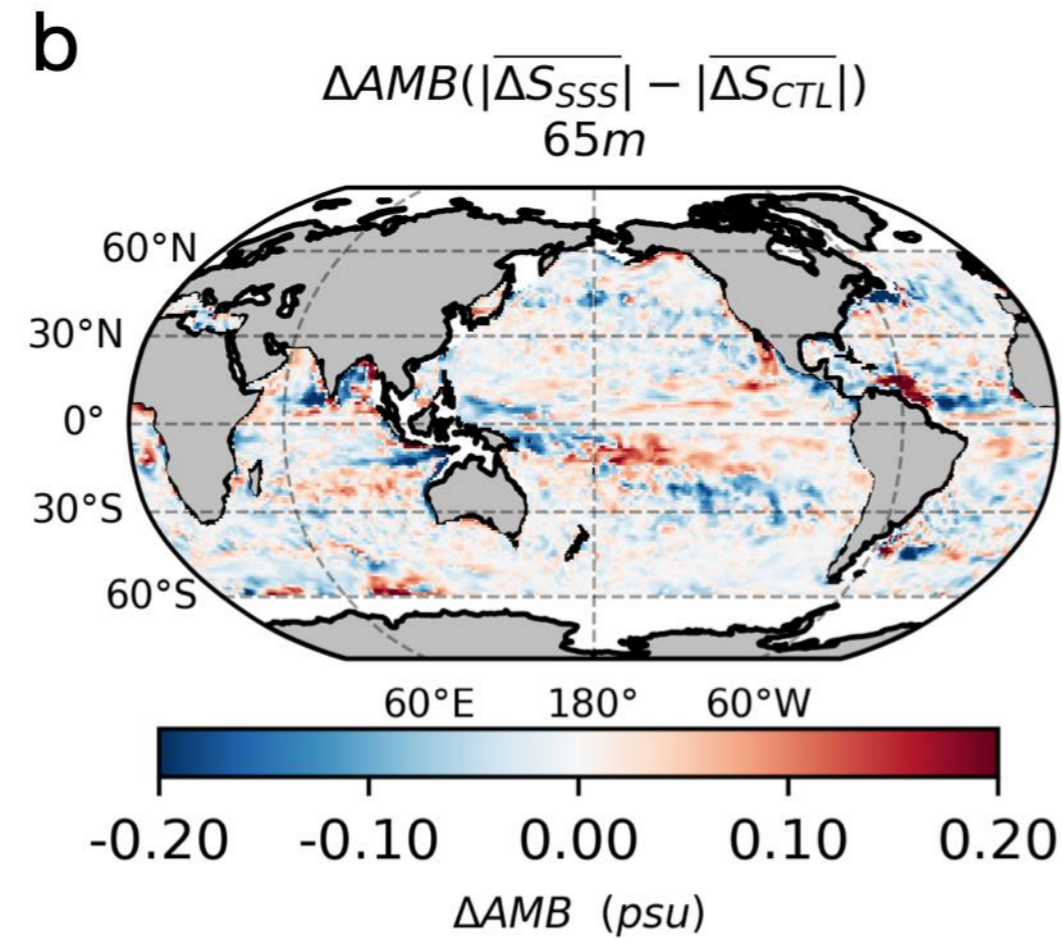
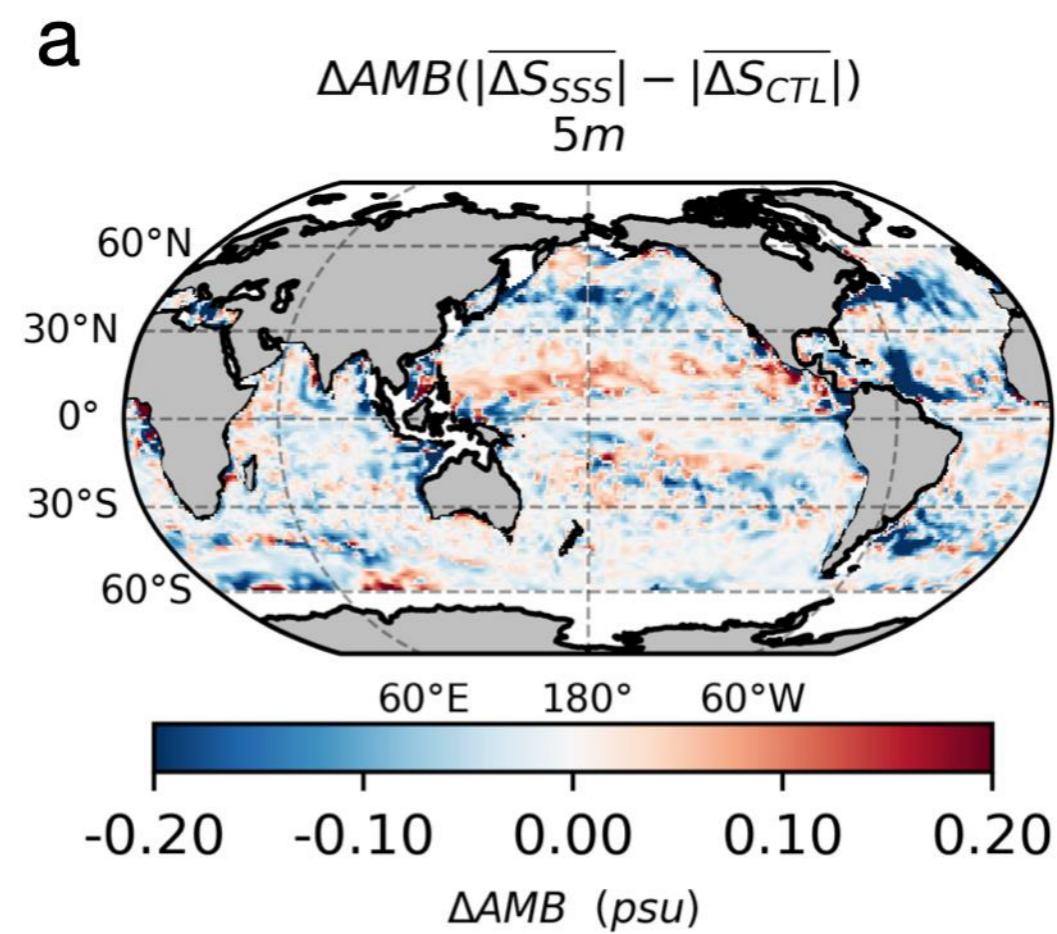
# Modeling System: NASA GEOS S2S 2

- NASA GEOS-S2S-2 employs AODAS (Atmospheric-Ocean DA System) + SSS
  - SST relaxation every 24 hours



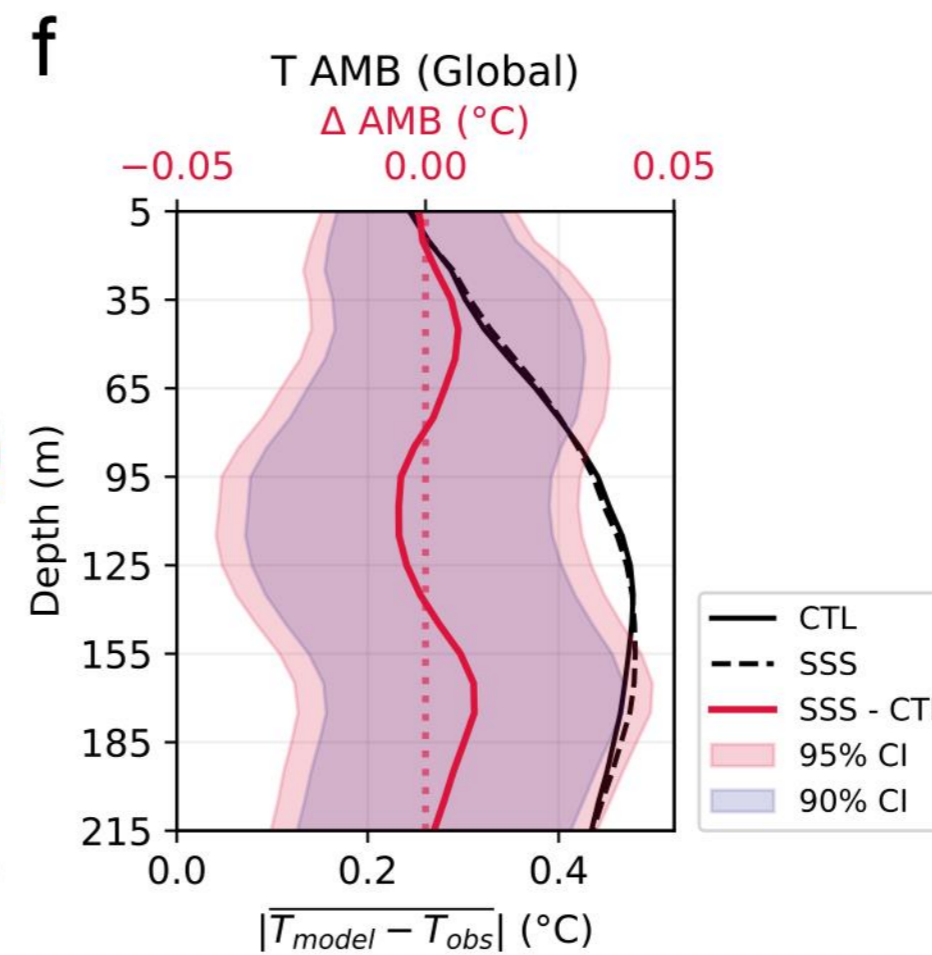
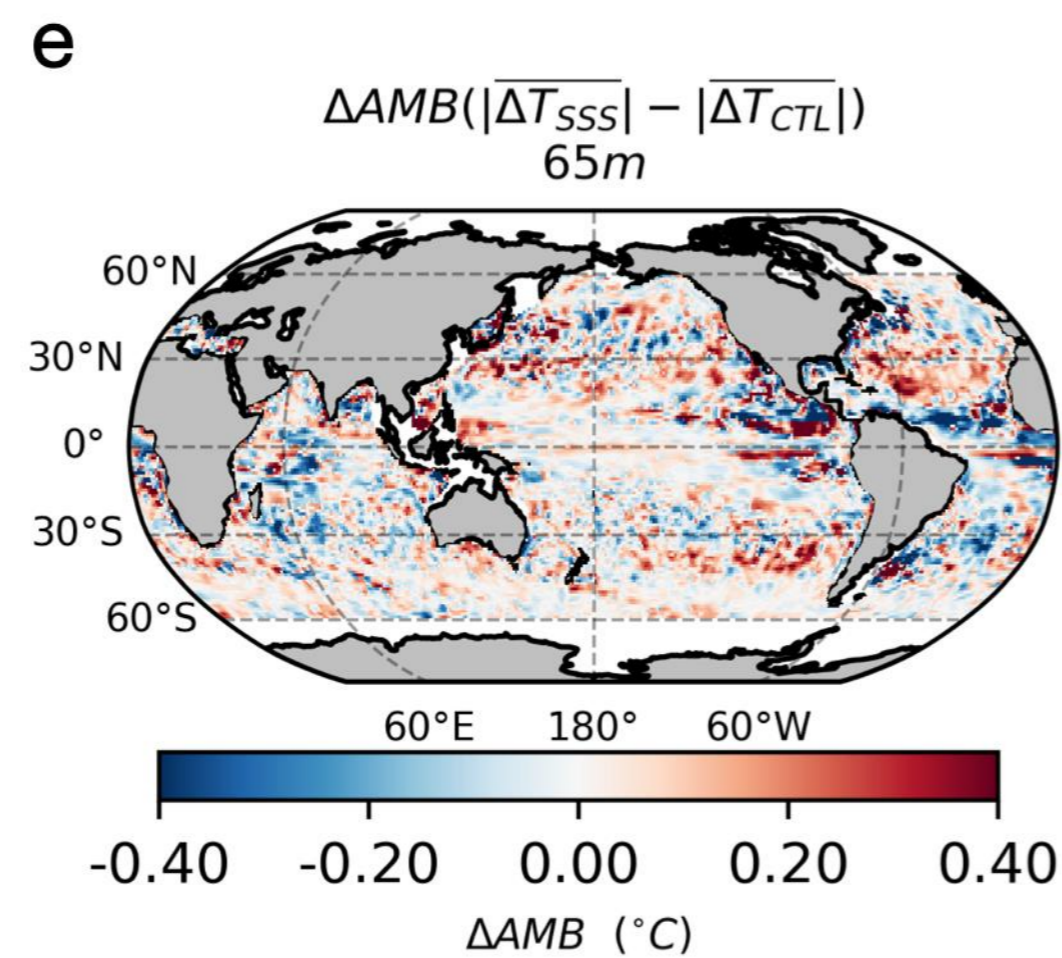
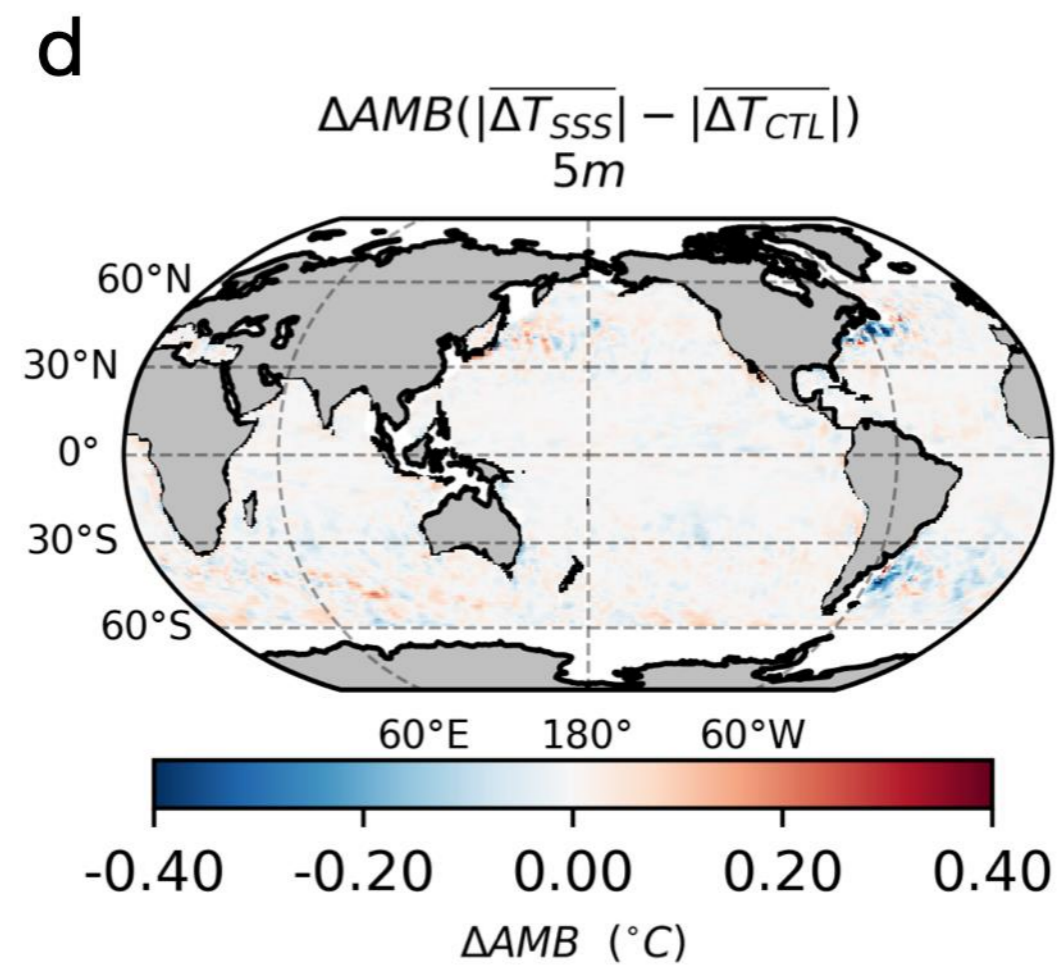
# SSS DA improves global time mean salinity

Salinity



- SSS DA reduces global mean upper-ocean Absolute Mean Bias (AMB)(vs Argo climatology)

Temperature



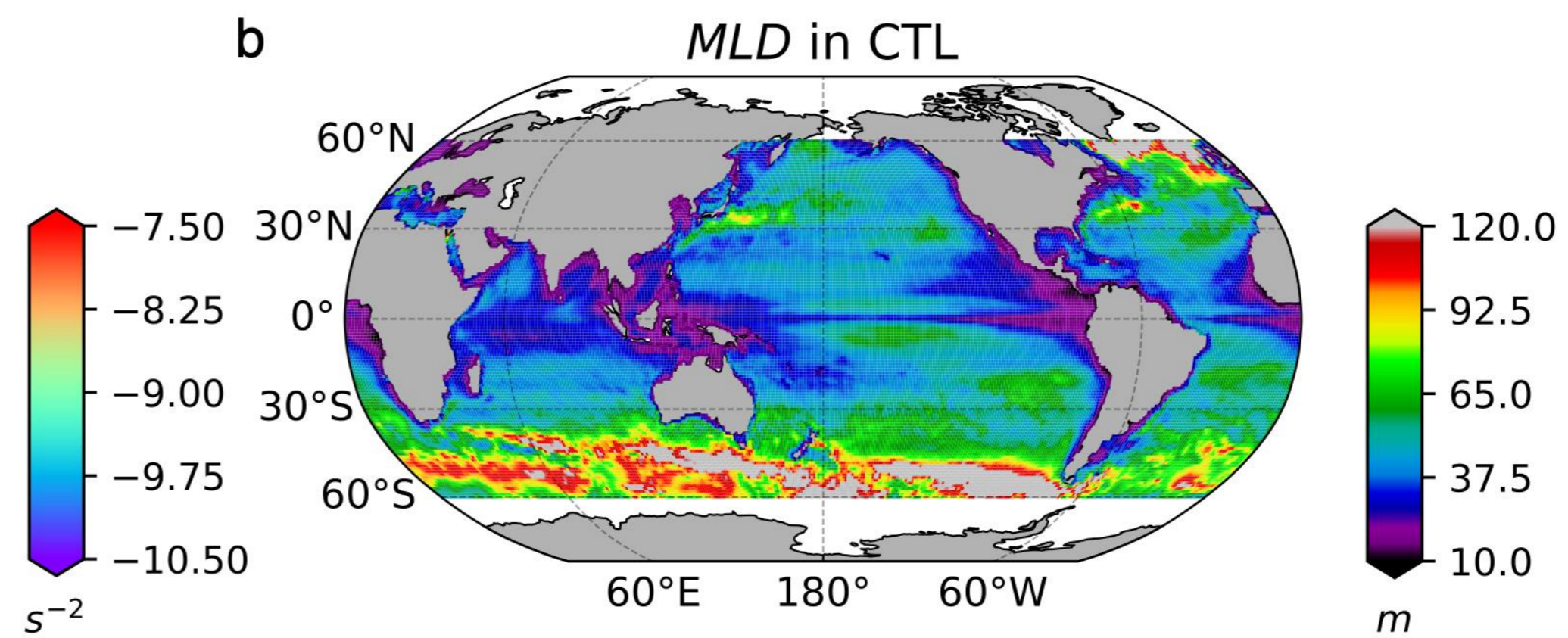
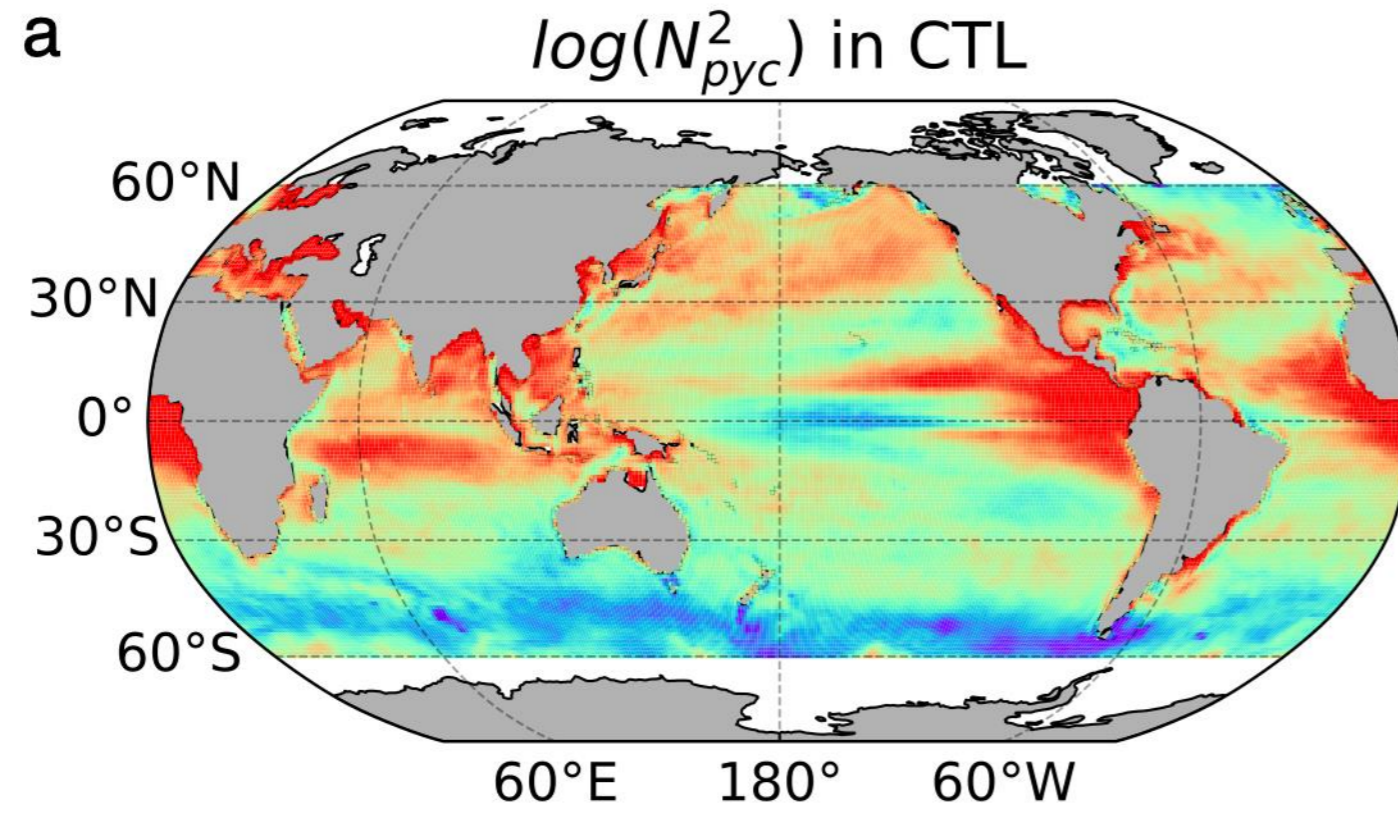
- Regionally varying change in AMB of temperature, hence no difference in global upper-ocean temperature AMB

# SSS DA modifies the time mean $N^2_{pyc}$ & MLD

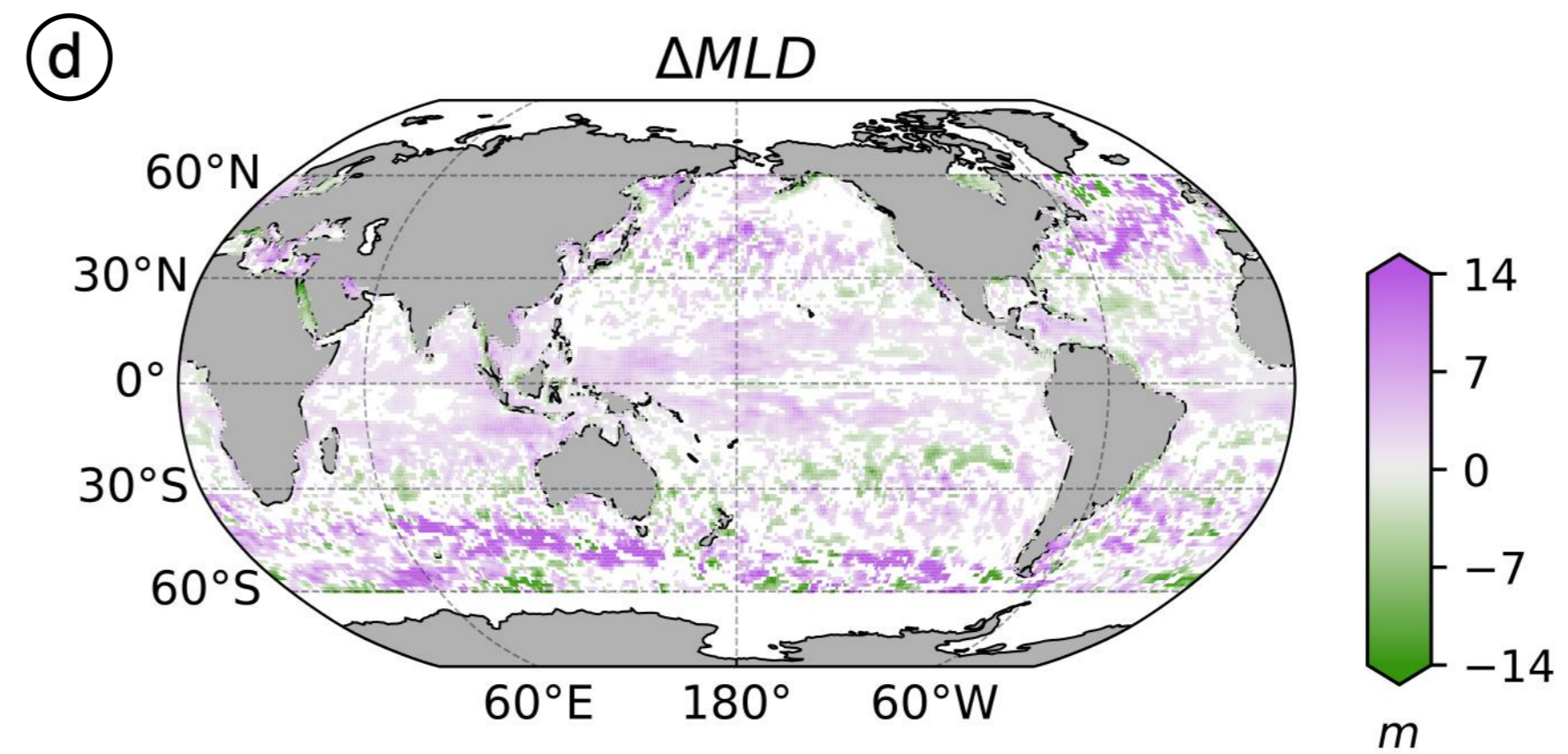
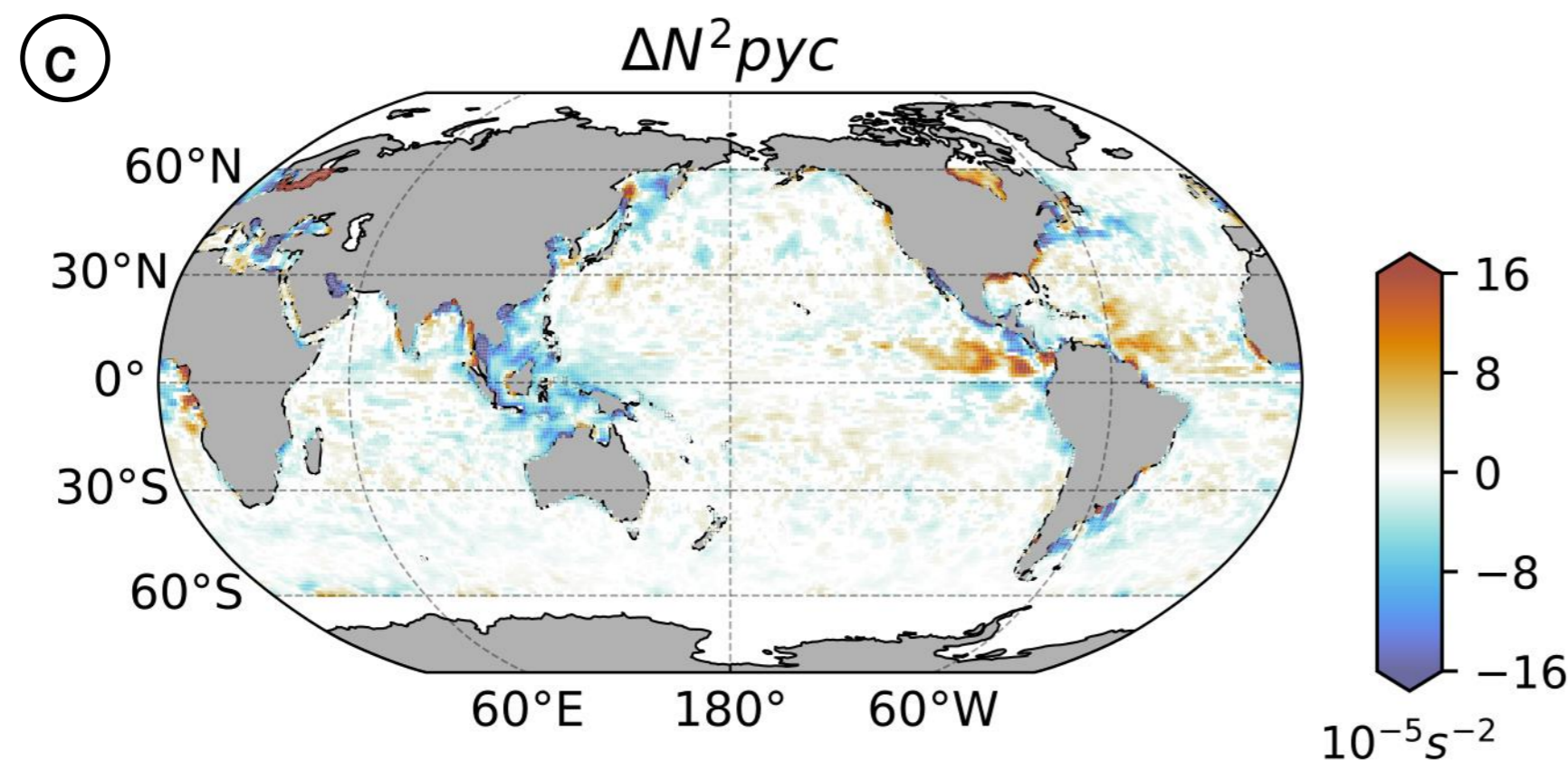
CTL time mean

$N^2_{pyc}$

MLD



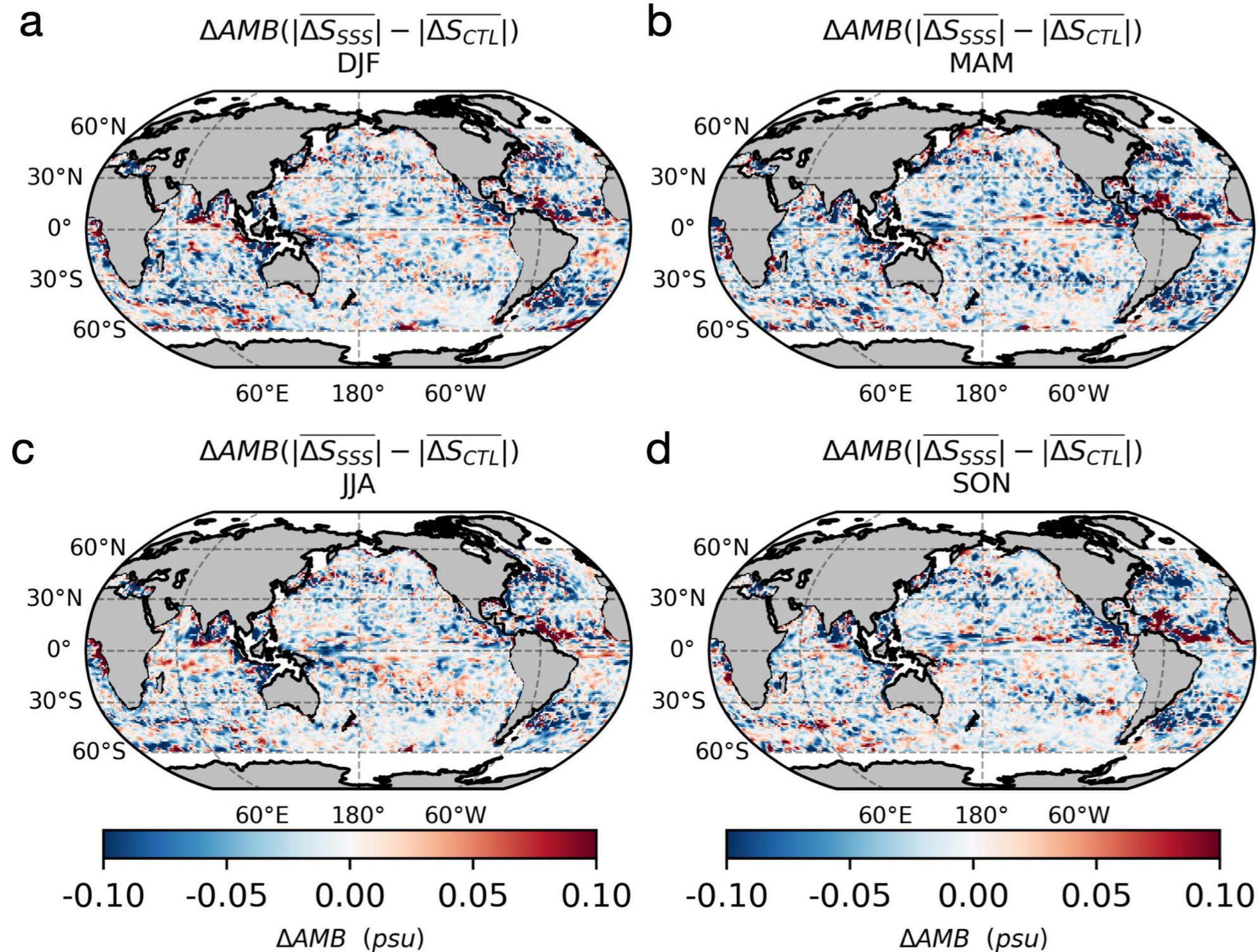
SSS - CTL



$\Delta N^2_{pyc}$  &  $\Delta MLD$  **NOT** always consistent with the  $\Delta S$ :

*SSS DA possibly impacts on atmospheric conditions (e.g., wind stress)*

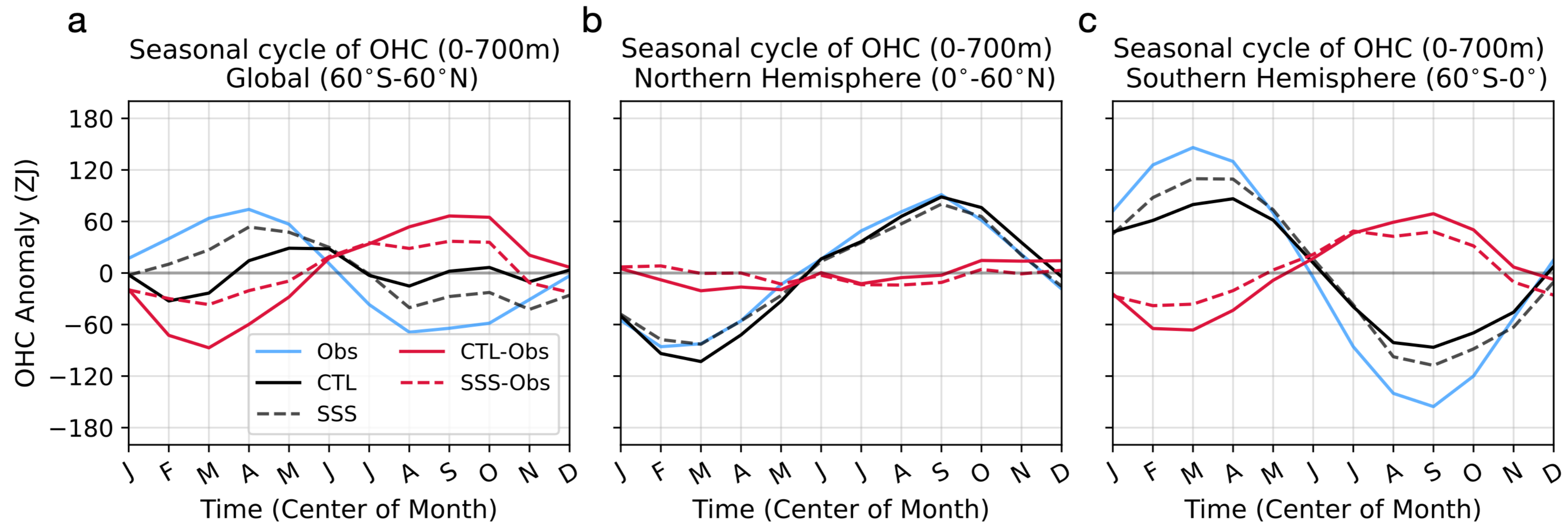
# Improved seasonal variability of the salinity



- Absolute Mean Bias (Models-Obs) is compared in each season

- **Reduced AMB of upper 50m salinity:** better representation of the seasonal variability of the upper 50m salinity with SSS DA

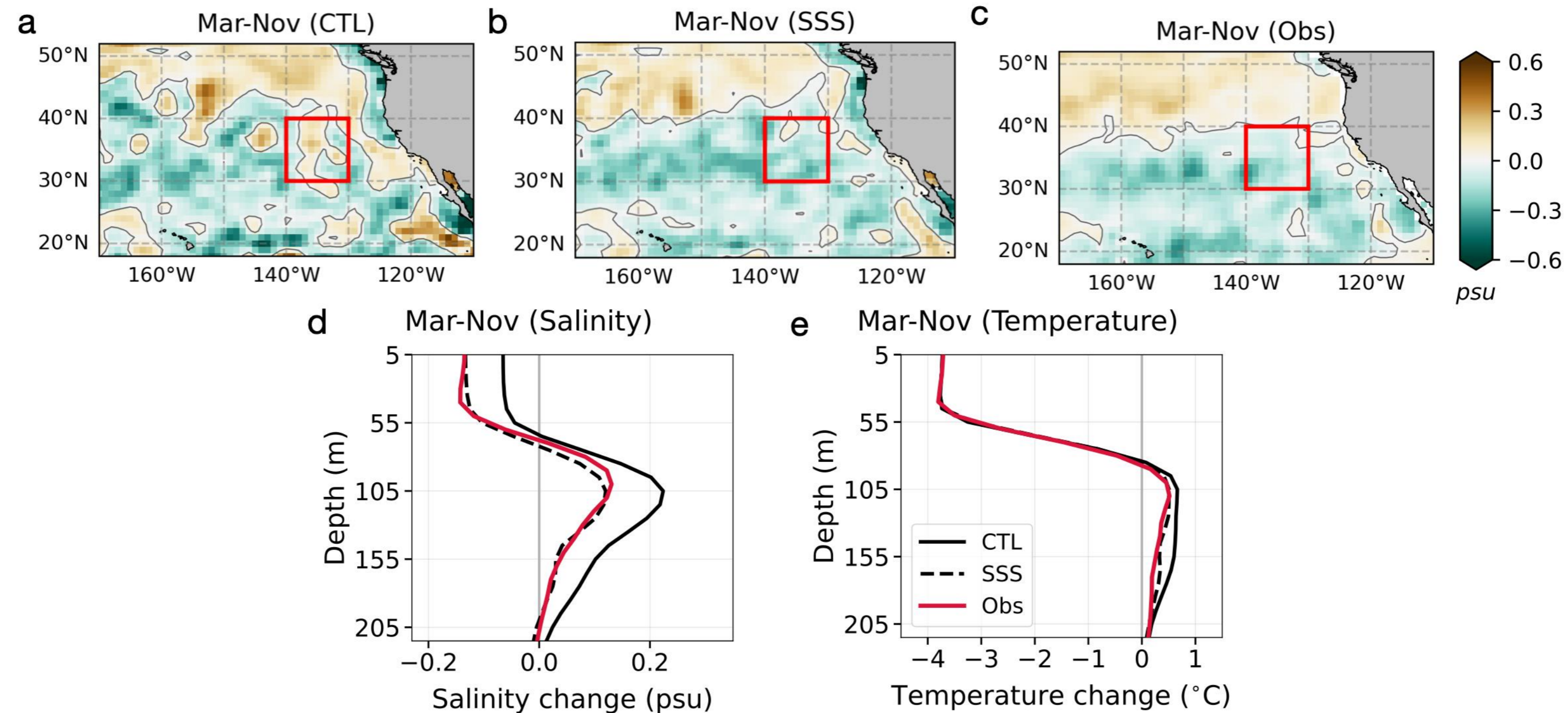
# Improved seasonal variability of OHC



- Seasonal variability of the OHC is compared to observation (Argo Climatology)
- Phasing/variability are better captured in the SSS run both in NH, SH, and therefore, globally
- **Better representation of the OHC (0-700m) reflects Improved seasonal variability of S/T**

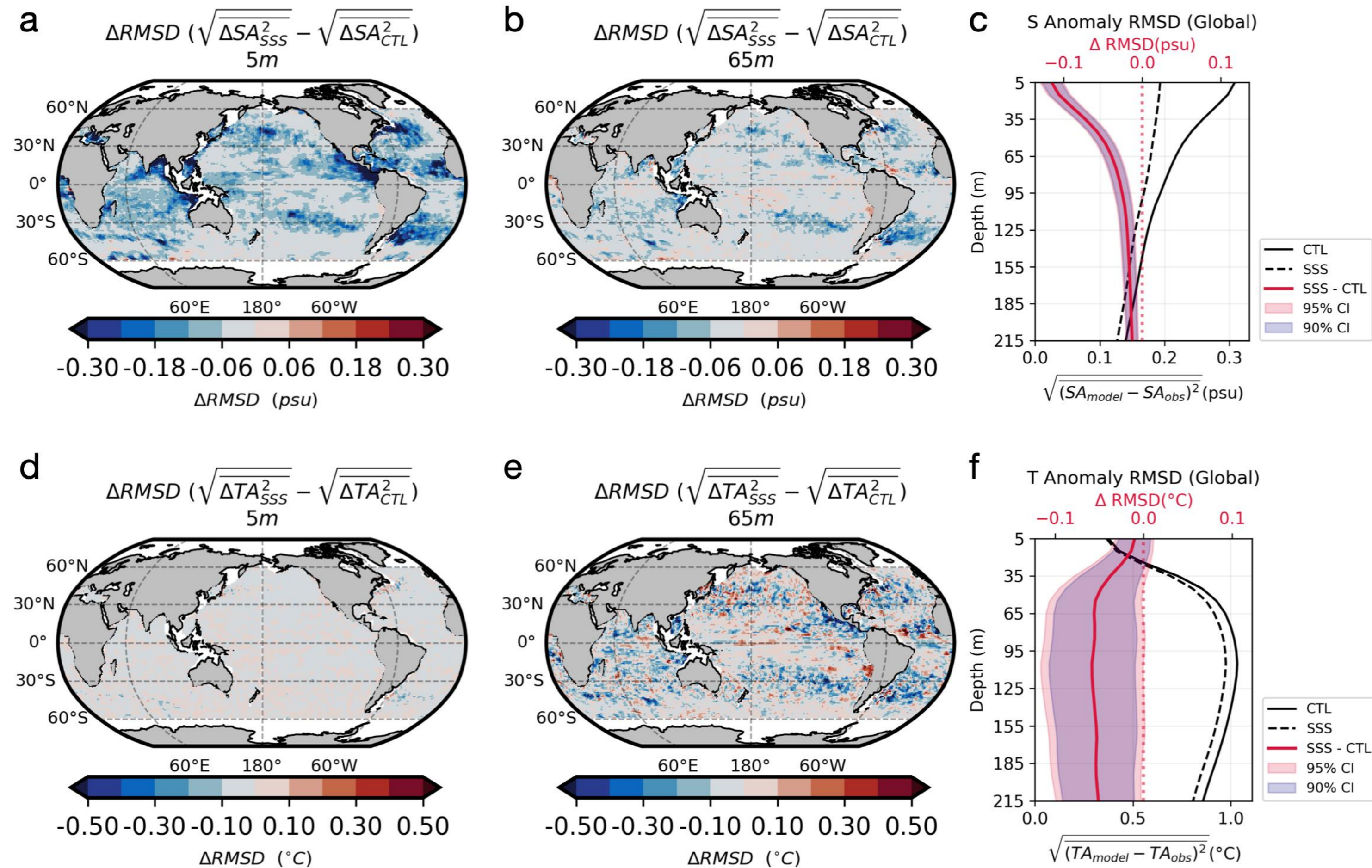
# Improved regional, wintertime freshening

Winter upper-ocean freshening in the northeast Pacific: only captured in the SSS run



- Better representation of the winter upper-ocean freshening (March–November) with the SSS DA
- Surface improvement affects (enhances) throughout the upper 200m temperature
- Great implication: Atmospheric Rivers contribute 70–90% of total winter precipitation in the subtropical NE Pacific, [freshening](#) the upper ocean (Giglio et al., 2025)

# Improved upper-ocean monthly anomalies

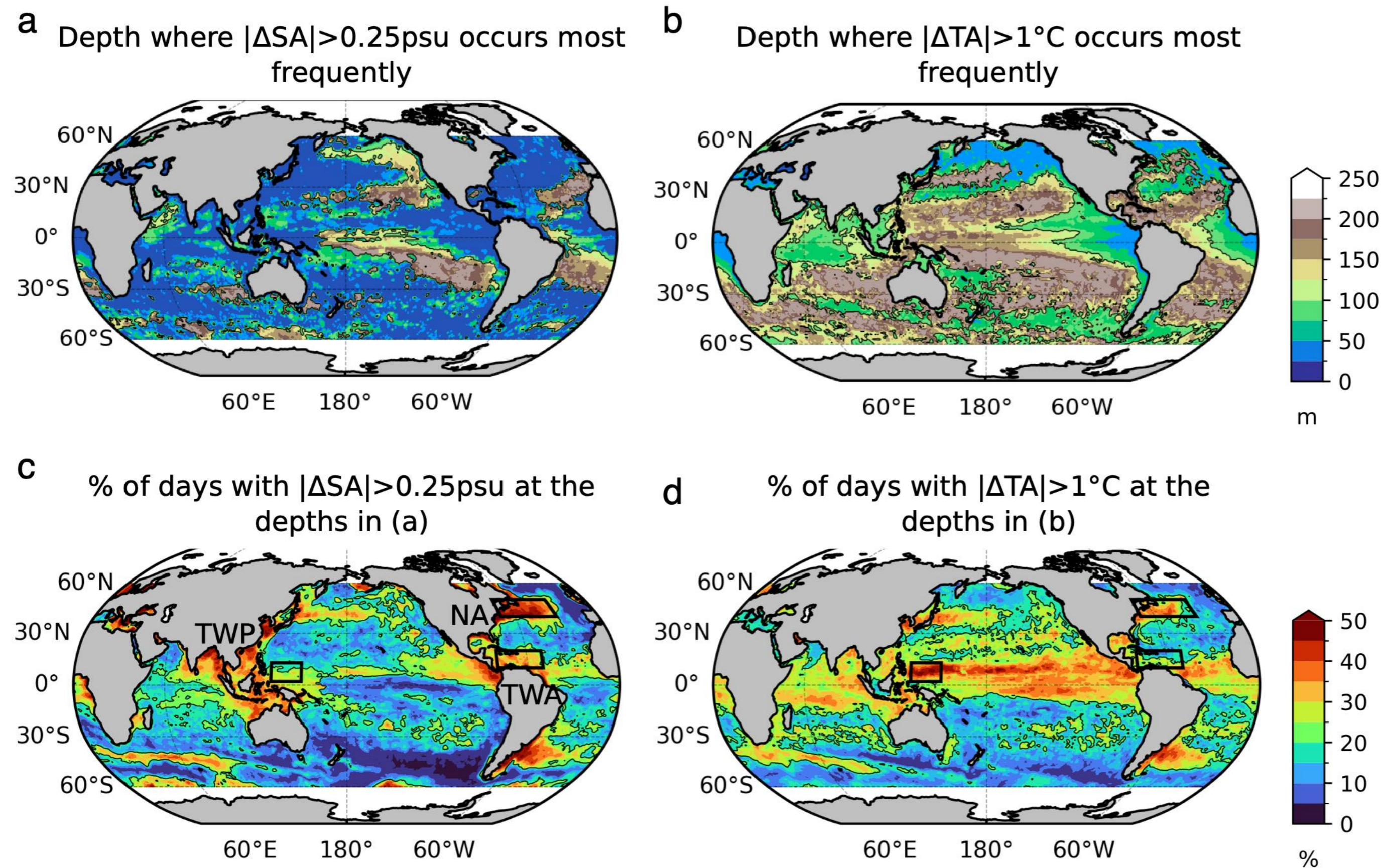


- Root Mean Squared differences (models-obs) of monthly SA/TA are compared

- **Reduced RMSD of upper-ocean salinity and temperature anomalies:** better representation of the monthly anomalies with SSS DA

# Global daily anomaly impact diagnostics

impactful modification of SSS DA on daily T/S anomalies throughout the upper ocean.



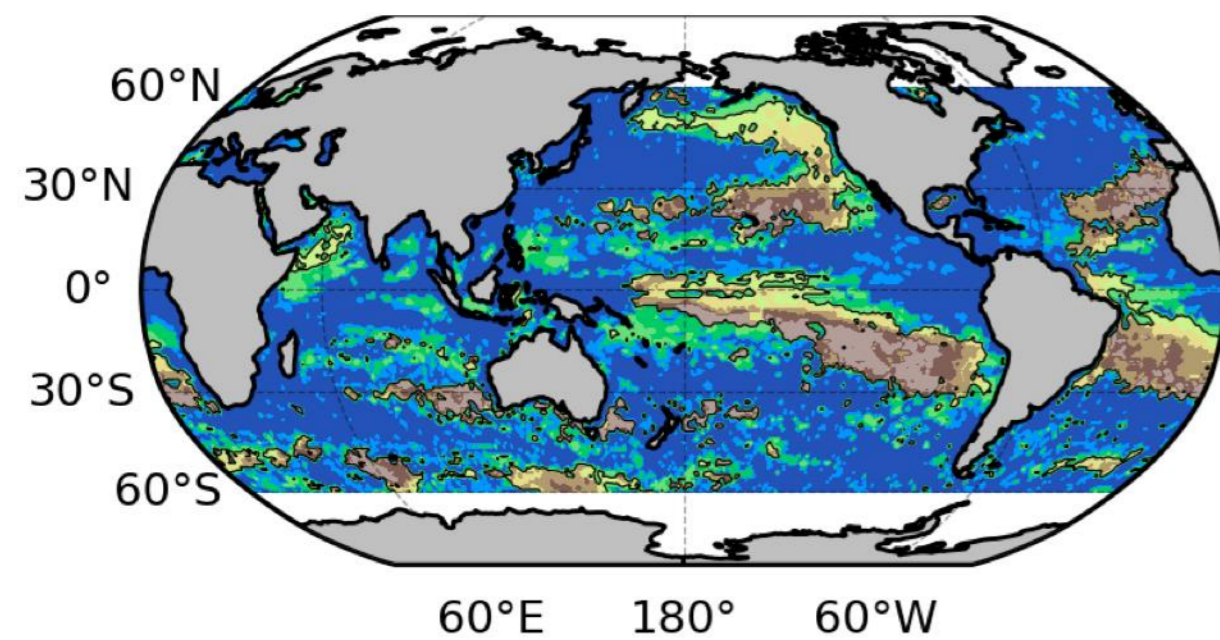
- SSS DA causes impactful change in SA/TA in more than 1/3 days, globally

- Depth at which impactful difference in SA/TA (SSS-CTL) is most frequent:  
**near-surface SA modification brings change in TA at deeper layer**

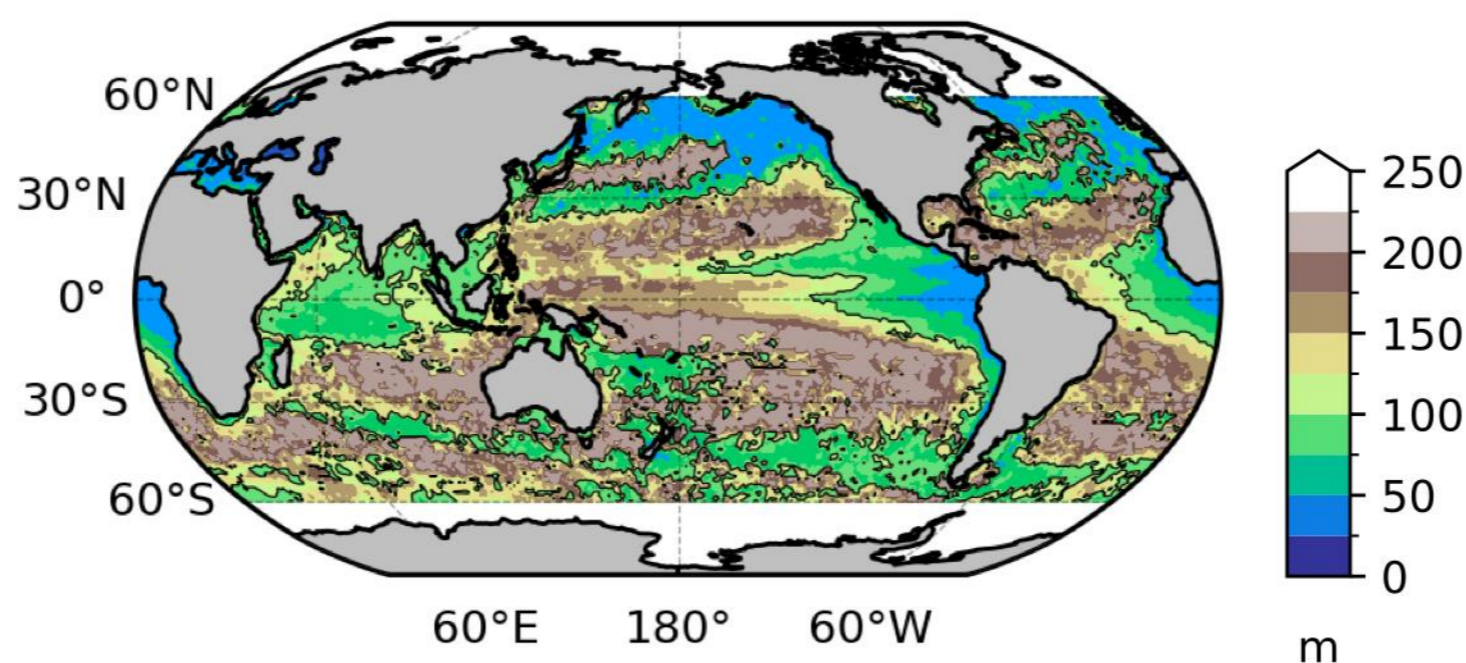
# Regional validation of improvement in SA/TA

Vertical profiles of RMSD of SA/TA are compared at a regional level: three representatives  
 (a) *Tropical Western Pacific (TWP)*; (b) *North Atlantic (NA)* & (c) *Tropical Western Atlantic (TWA)*

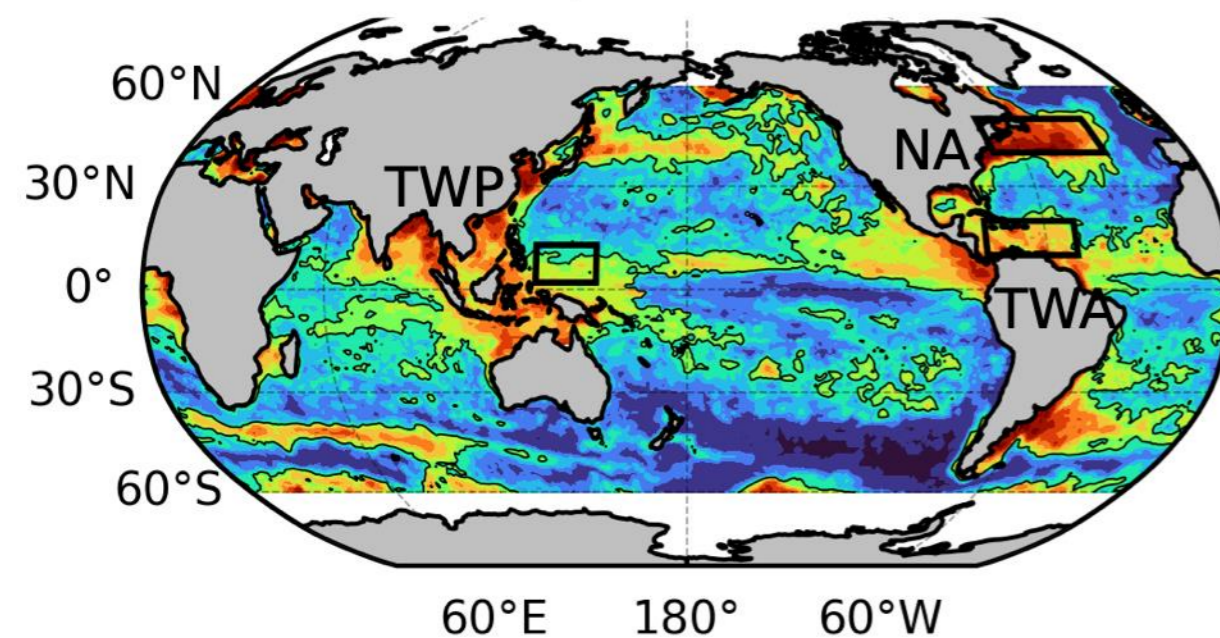
**a** Depth where  $|\Delta SA| > 0.25 \text{ psu}$  occurs most frequently



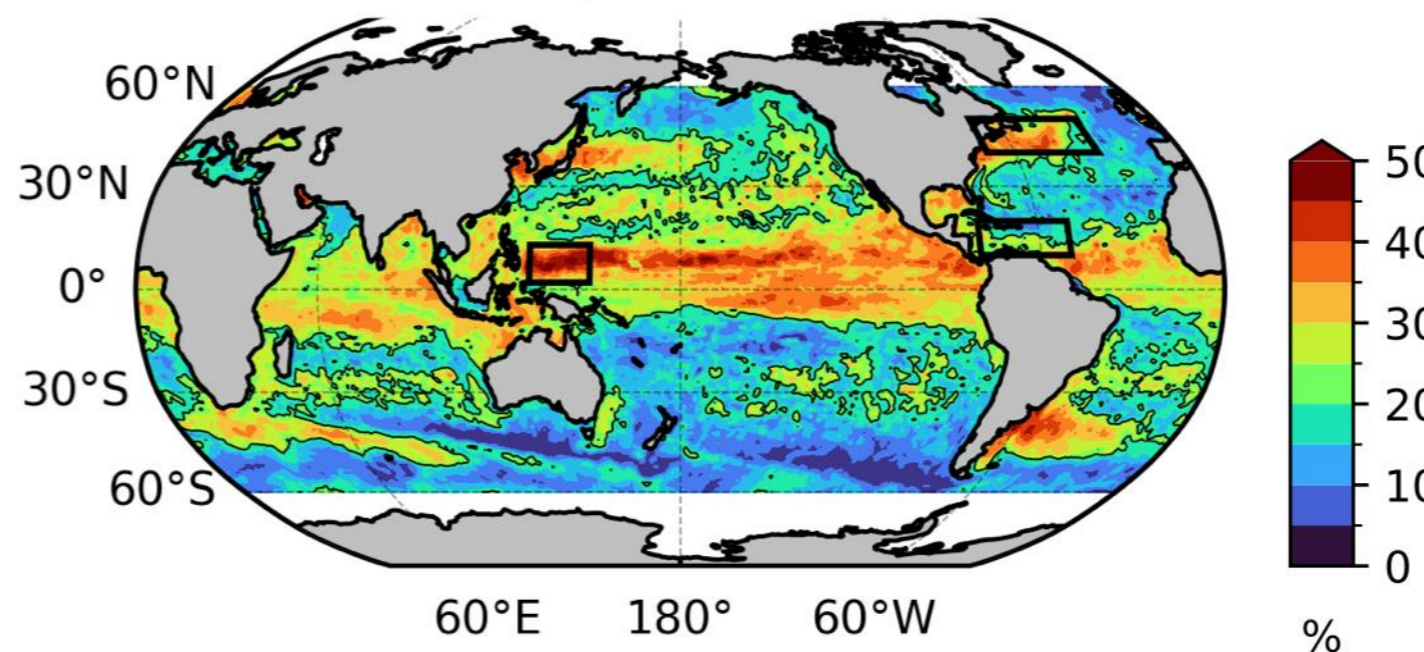
**b** Depth where  $|\Delta TA| > 1^\circ\text{C}$  occurs most frequently



**c** % of days with  $|\Delta SA| > 0.25 \text{ psu}$  at the depths in (a)



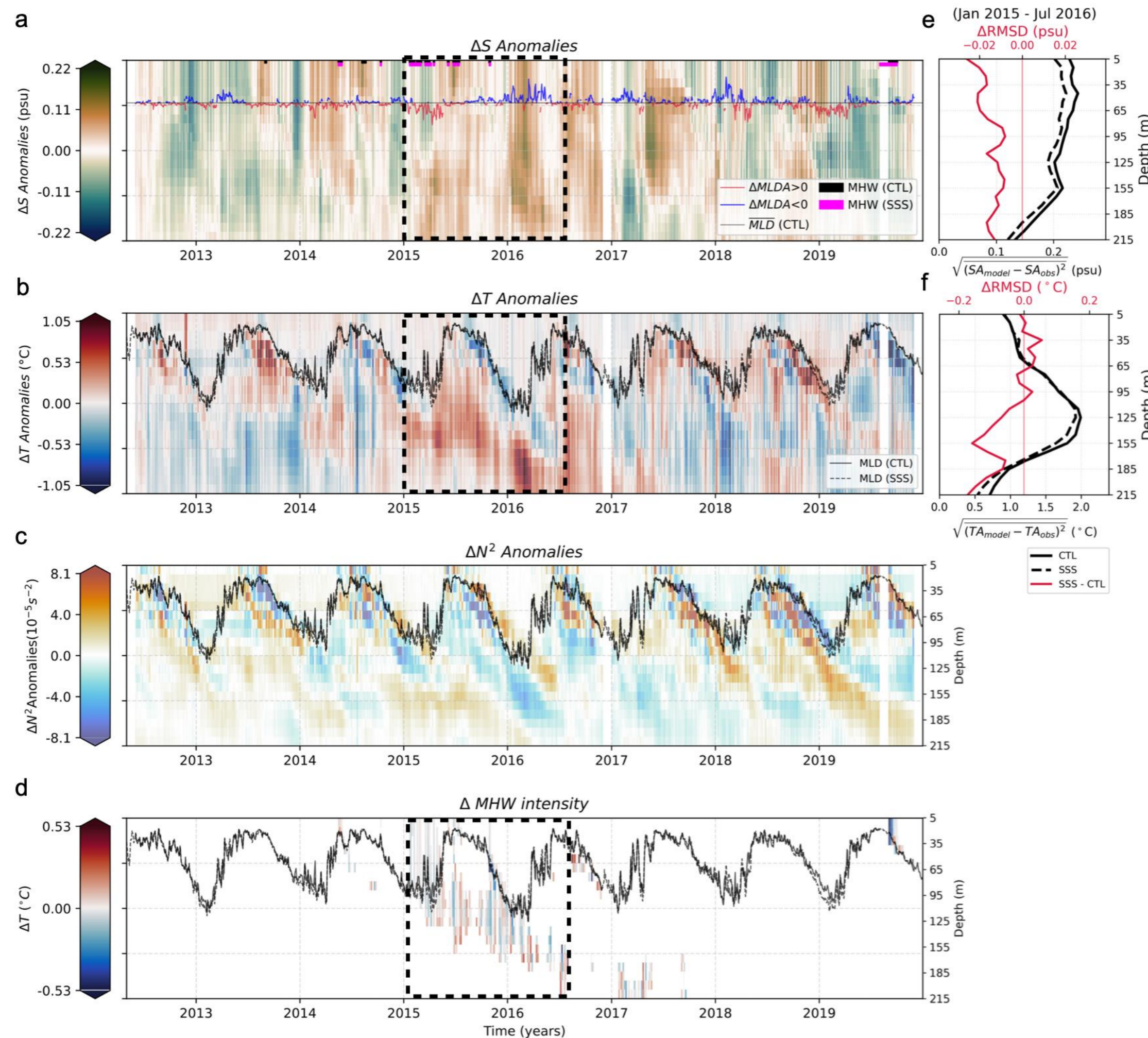
**d** % of days with  $|\Delta TA| > 1^\circ\text{C}$  at the depths in (b)



Region	% of days with $ \Delta SA  > 0.25 \text{ psu}$	% of days with $ \Delta TA  > 1^\circ\text{C}$
Tropical Western Pacific (TWP)	infrequent (< 25%)	frequent (> 50%)
North Atlantic (NA)	frequent (> 50%)	frequent (> 40%)
Tropical Western Atlantic (TWA)	frequent (> 40%)	infrequent (< 25%)

# Subsurface anomalies during the extreme event

Improved representation of the subsurface TA during the 2014-2016 northeastern Pacific MHW



- Vertical profiles of  $\Delta SA$ ,  $\Delta TA$  and  $\Delta N^2 A$  (SSS-CTL)

- SSS DA-driven  $\Delta SA$  cause subsurface temperature anomaly modification, **most notably during the subsurface MHW event (>1degC)**

- During this period, RMSD of  $\Delta SA$ ,  $\Delta TA$  decreased in SSS run: **SSS DA enhances representation of subsurface  $\Delta TA$  during the significant extreme**

# Summary

## SSS DA Improves:

- Time mean, seasonal cycle, and detrended deseasonalized anomalies of T and S, hence
  - OHCA in the ML & MHW intensity
- Capture wintertime freshening due to AR in NE Pacific more accurately

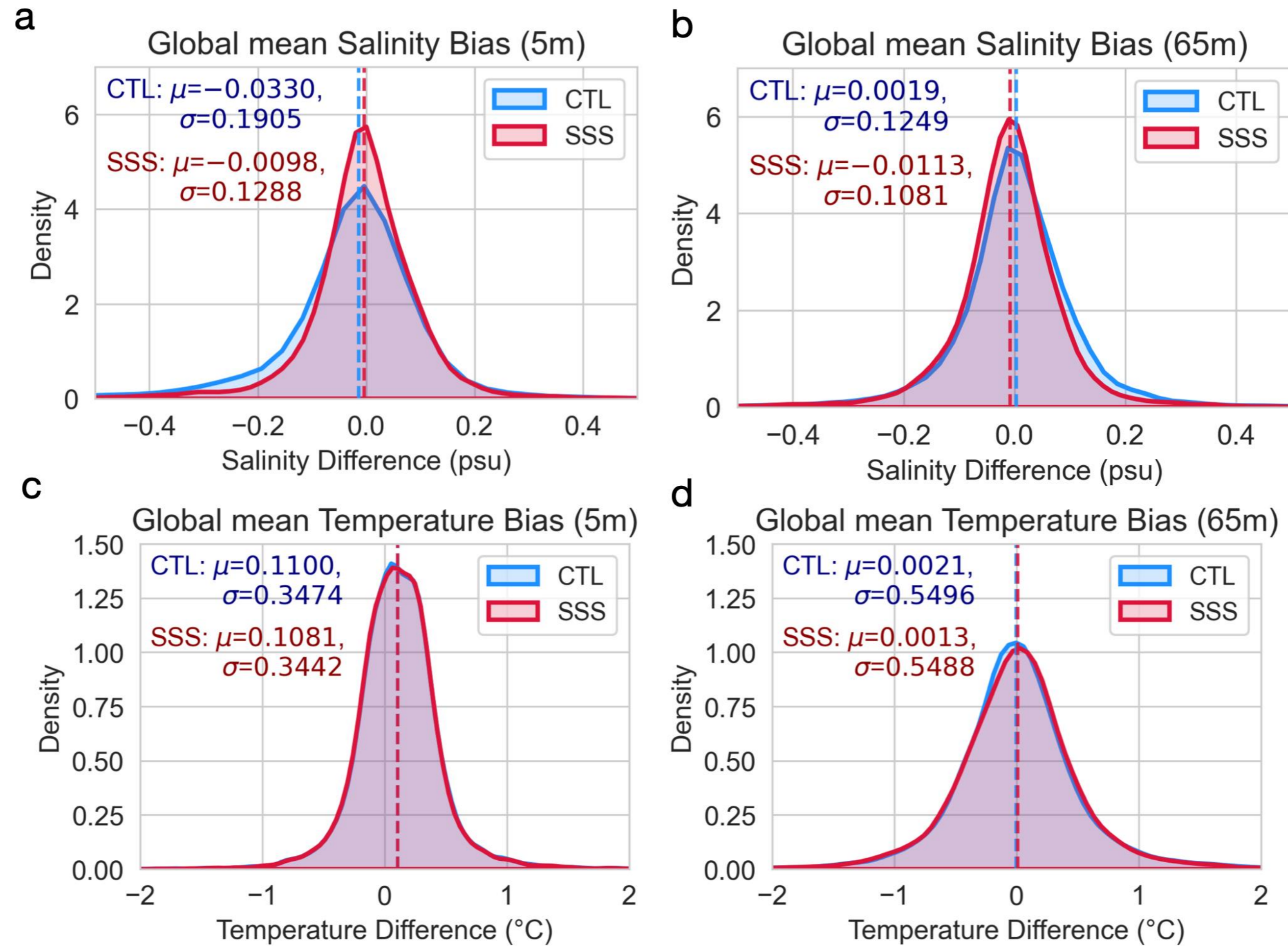
*Results highlight the critical role of satellite salinity constraints for representation of multi-timescale and multi-spatial scale upper ocean states*



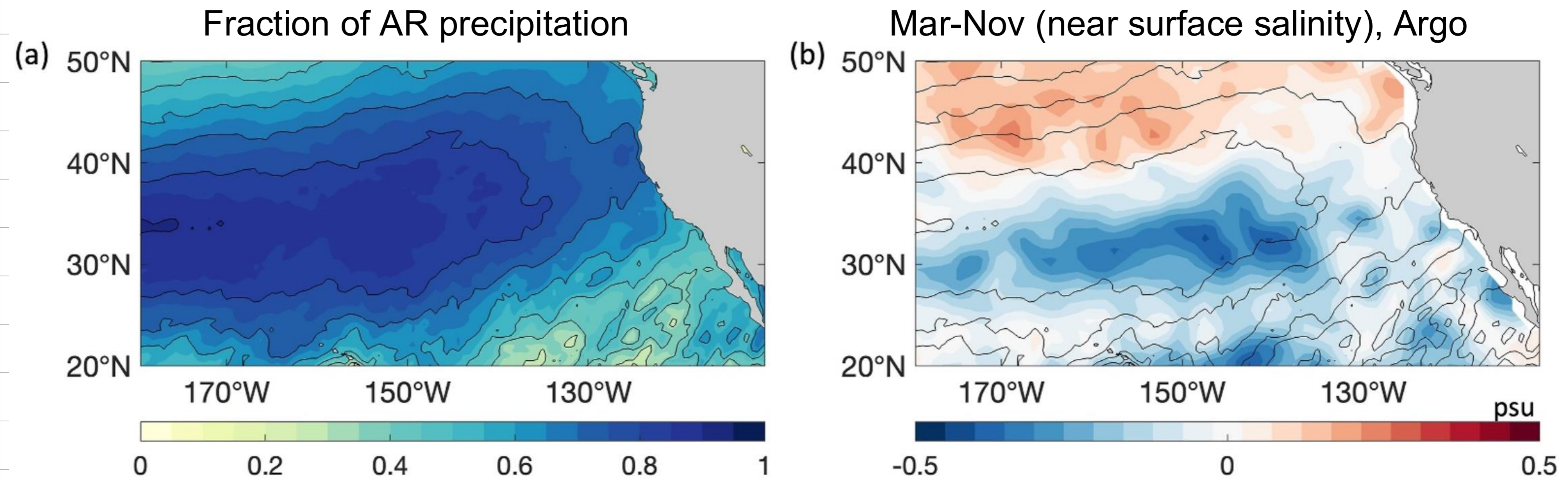




# SSS DA improves global time mean salinity



# DJF Precipitation by Atmospheric Rivers & SSS in the NE Pacific



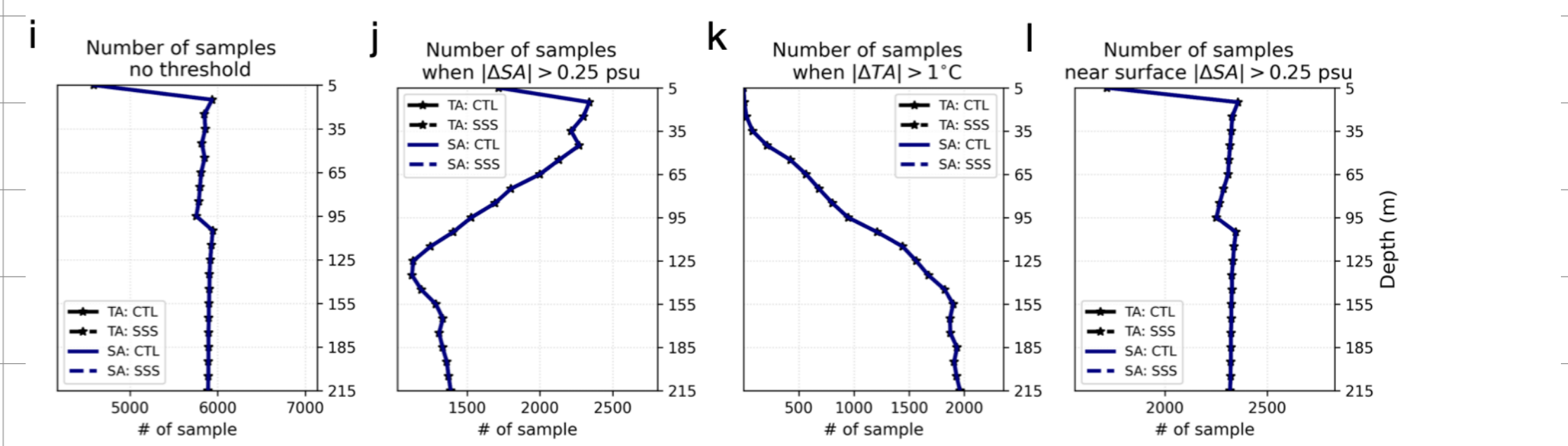
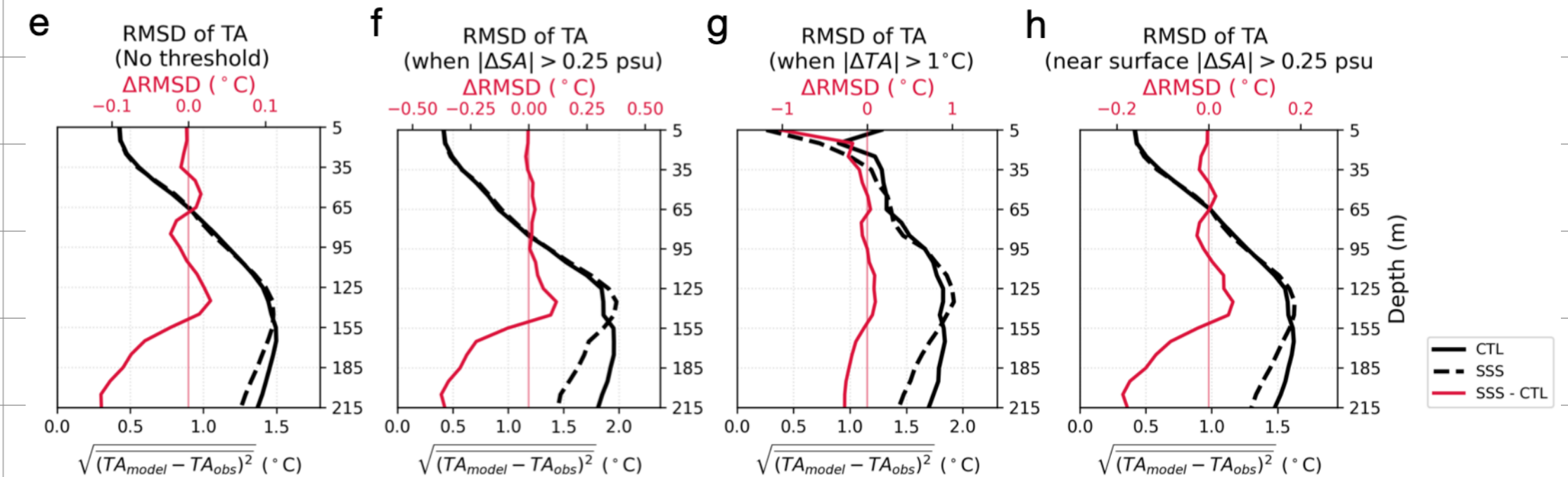
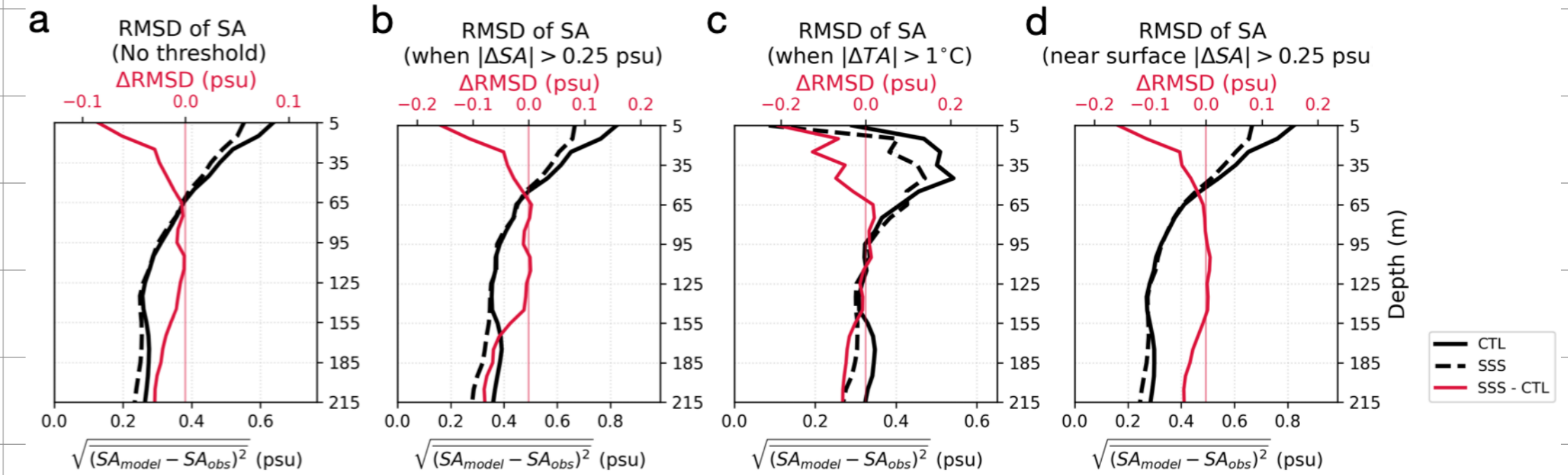
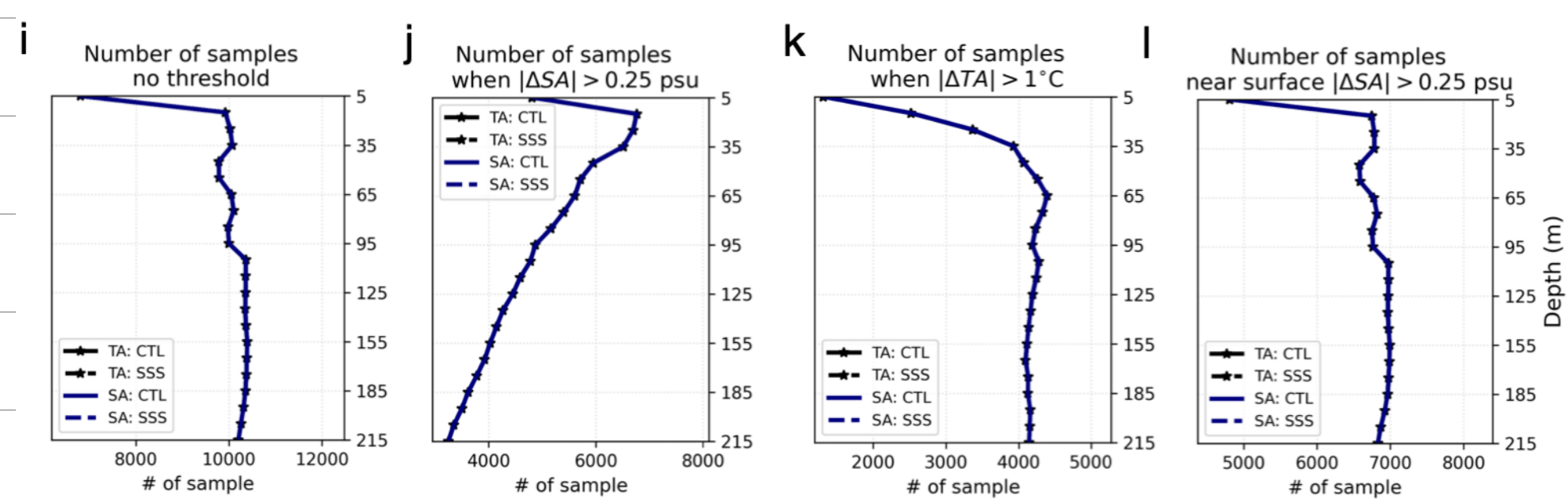
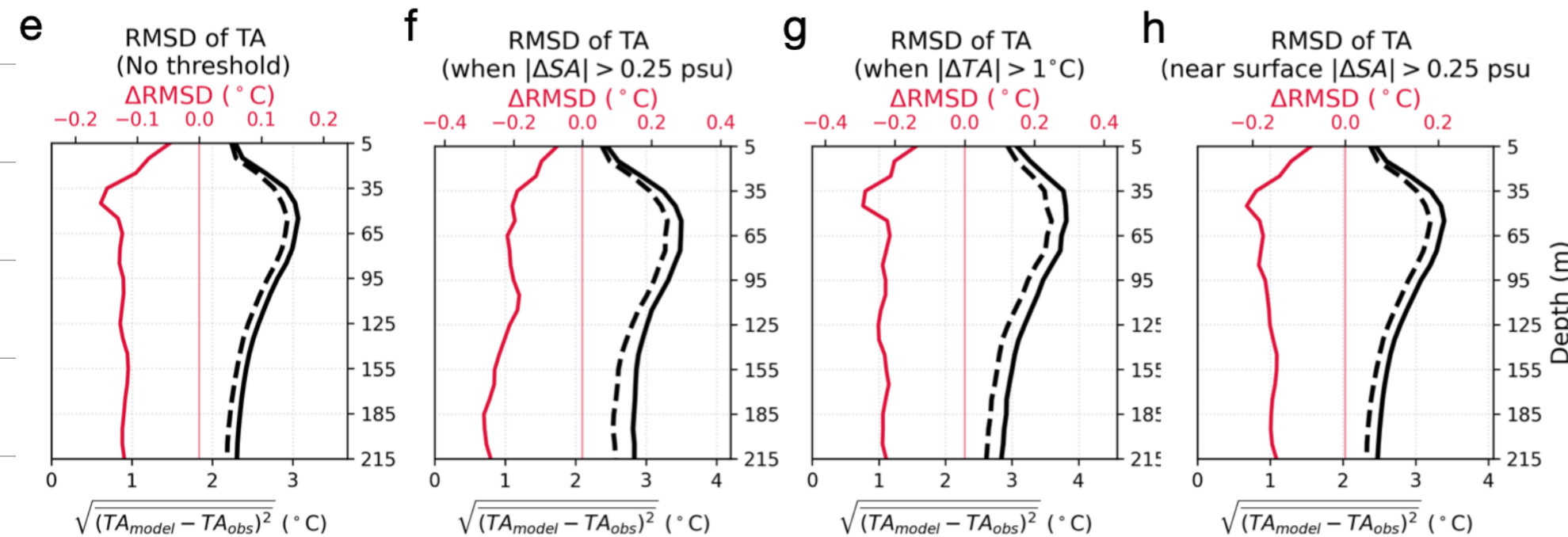
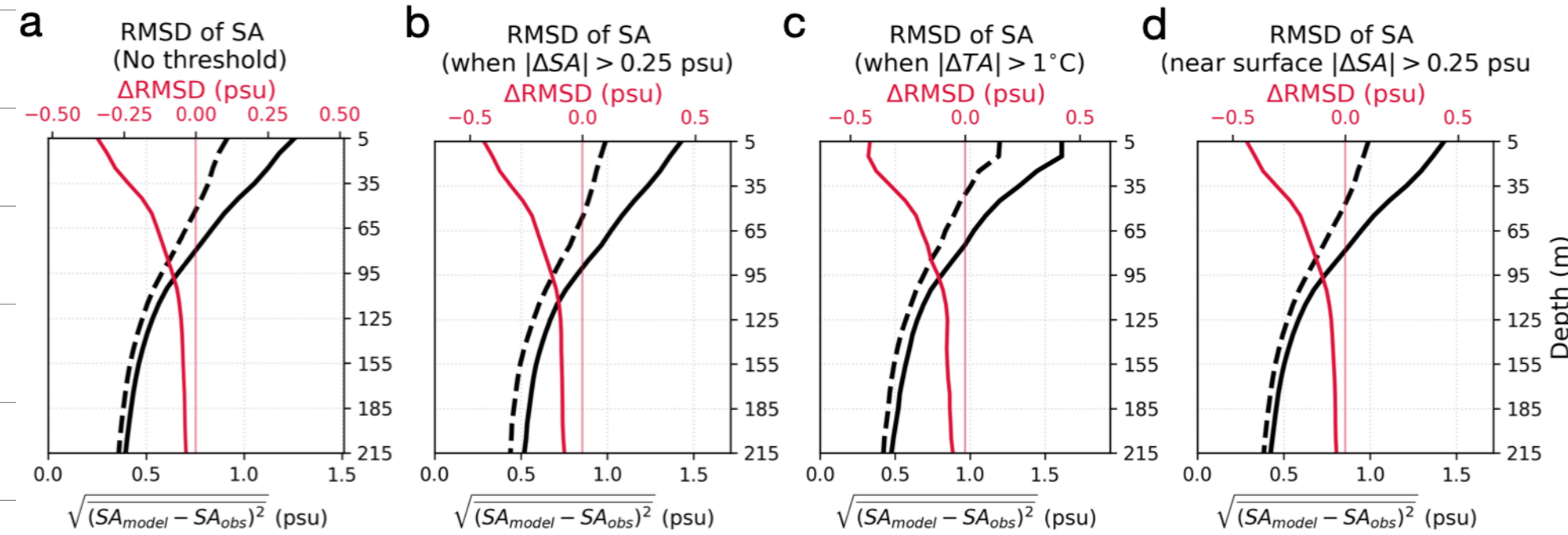
Giglio et al. 2025

- Atmospheric Rivers contribute 70–90% of total winter precipitation in the subtropical NE Pacific, [freshening](#) the upper ocean
- $(SSS_{\text{March}} - SSS_{\text{Nov}}) < 0$

# SSS DA improves SA/TA in the NA/TWA

NA

TWA



# SSS DA improves SA/TA in the NEP

